Case Study:

The results of IMPCO's GM 3.0 liter certified engine program

Evaluation of a GM 3.0 liter four cylinder engine to determine system criteria and design required to comply with ARB's 2001 and subsequent LSI certification regulations.

This presentation highlights the results of each level of development from:

- Basic system development
- Catalyst introduction
- Introduction of customized closed loop systems.

IMPCO development program achieved a significant reduction in exhaust gas levels over the base engine configuration with comparable engine power output and driveability

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Step #1

Setting the test protocol to demonstrate that emissions can be achieved while retaining power & Torque. Also to meet durability for 2004.

An OEM open loop production engine was tested for baseline emissions and power/torque characteristics

IMPCO System Development

- Closed loop gas valve added to IMPCO carburetor
- Idle and power settings were adjusted for desired emissions and controller authority
- IMPCO regulator location optimized for transient response
- Electric lock-off installed
- IMPCO 3-way catalyst installed
- Calibrated emissions air-gas valve installed
- Fitting from secondary reference chamber cover routed to closed loop control solenoid
- 3-way closed loop control solenoid was added as a modulated switching device between air valve vacuum (normally closed) and atmospheric reference pressure (normally open)
- Software calibrated to achieve a balance of low Nox, HC, and CO emissions
- Horsepower and torque curves plotted

In Vehicle Development

During dyno system development, a simultaneous on-vehicle evaluation was taking place.

A current production open loop truck with identical engine/intake system was tested at the OEM to evaluate and baseline performance of a current production vehicle. The OEM performed the following tests on the vehicle:

OEM in vehicle Open Loop performance tests:

- Emissions
- Drawbar pull
- Acceleration
- Gradeability
- Driveability was measured subjectively in a pass/fail type criteria

Truck was shipped to IMPCO and immediately tested to correlate IMPCO performance test data with the OEM data.

IMPCO tested the vehicle for the following criteria:

IMPCO in vehicle Open Loop baseline performance tests:

- Emissions
- Drawbar pull
- Acceleration
- Driveability

IMPCO in vehicle Closed Loop development:

A duplicate closed loop fuel and exhaust system to that tested on the dyno was developed and installed on the truck.

The Closed Loop truck was tested and compared to the Open Loop.

IMPCO in vehicle Closed Loop performance tests:

- Emissions
- Drawbar pull
- Acceleration
- Driveability

Key members of the engineering team visited the OEM to review their test procedures and answer questions concerning the fuel system and its development.

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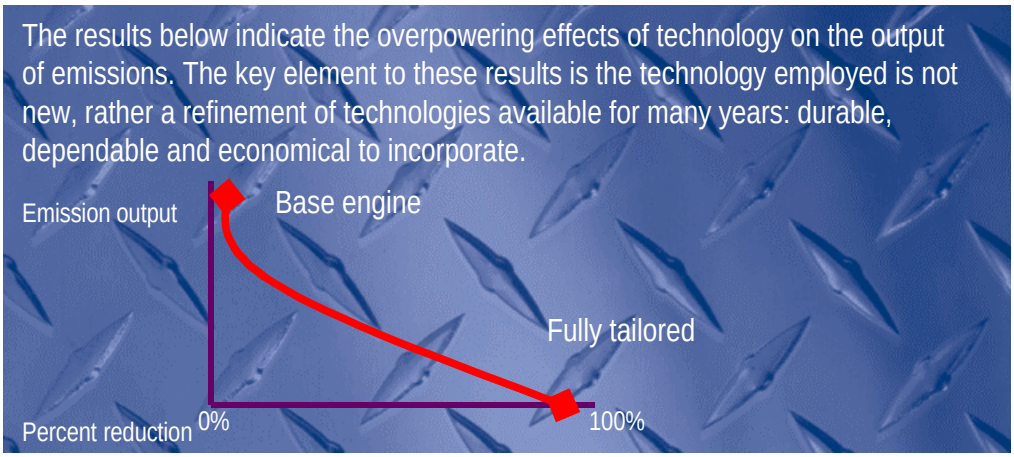

Test One - Open Loop -No Catalyst
Test Two - Commander I (low CO controller) - No Catalyst
Test Three - Commander II (custom program) + IMPCO Catalyst

	Test One	Test Two	Test Three
Nox, g\hp-h	24.92	12.47	0.47
CO,g\hp-h	0.01	3.28	0.13
HC,g\hp-h	1.65	1.13	0.13
Nox+HC,g\hp-h	**26.57**	**13.6**	**0.6**

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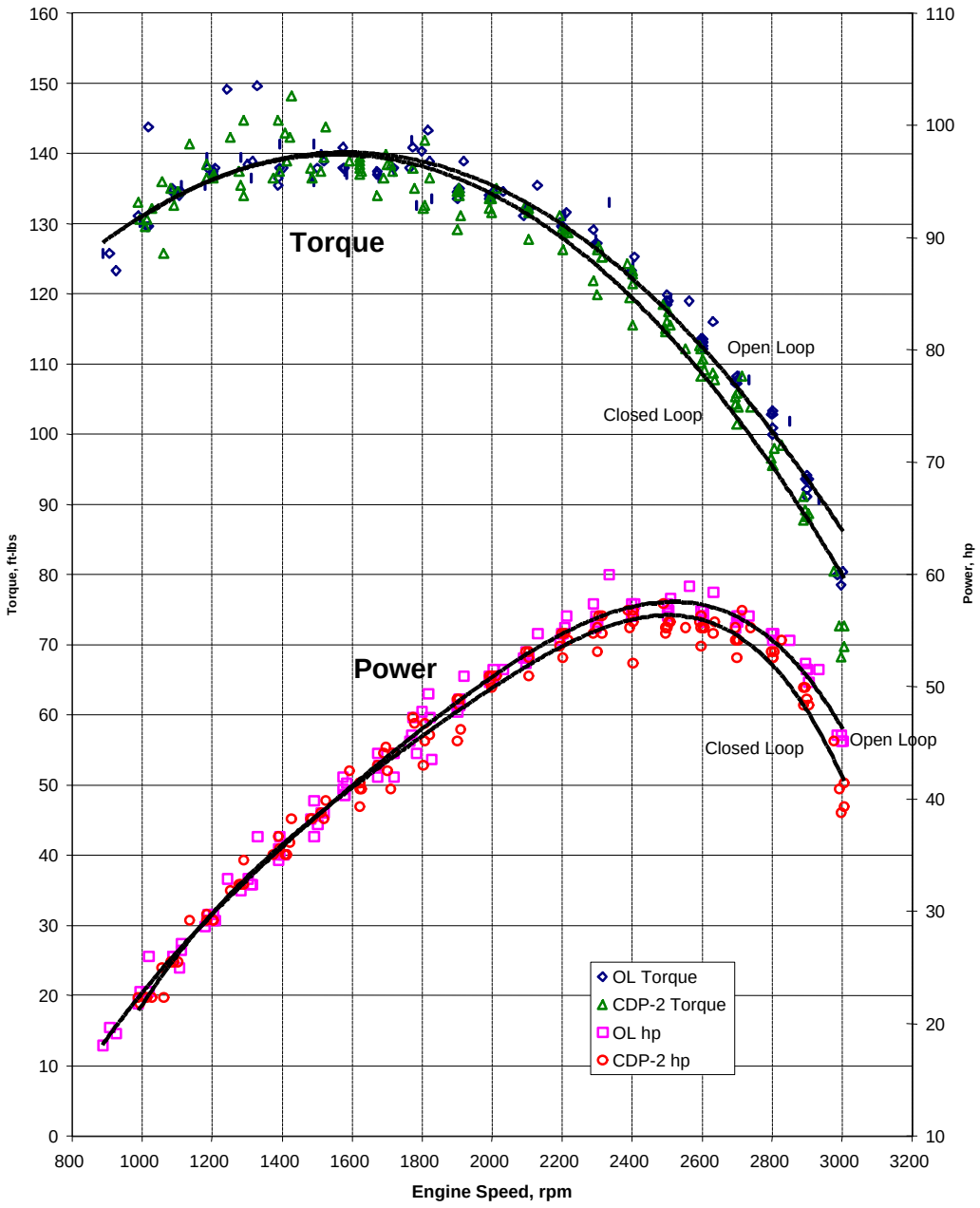
Appendix 2: Dynamometer Performance Curves



Open Loop-> AV1-14 ag/v, 1.8%CO WOT setting
Closed Loop-> CDP-2r7, CAT installed

17-Dec-98

Appendix 3: In vehicle Performance Testing

Open Loop Baseline Test

Truck tested as shipped, not optimized.

for all tests; *Transmission Sump Temp= >160F*
Hydraulic Sump Temp= >150F
Engine Oil Sump Temp= >200F

GM 3.0 liter Cushion truck w/ 2.5 ton capacity - 9600 lb vehicle

Emissions Test

Condition	Engine Speed	%CO	HC, ppm	%O2
Idle	800	0.09	100	1.26
High Idle	2900	0.05	20	3.08
Tilt Relief	2800	0.04	20	1.8
Trans Stall	2100	0.03	71	1.27

Performance Tests

Acceleration through 50ft from standstill

Condition	method 1	method2	method3
No Load	4.87	4.75	5.7
Loaded (5000lbs)	5.27	5.05	6.55

method 1: Lift brake and Jab throttle at same time
method 2: Lift brake and wait until transmission engagement, then Jab throttle
method 3: Lift brake, Jab throttle and Pull + Hold Tilt Relief at same time

Drawbar Pull

Ave Force (lbs)	5670

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Appendix 3: In vehicle Performance Testing con't

IMPCO/GM 3.0 liter Cushion truck w/ 2.5 ton capacity - 9600 lb vehicle

Closed Loop Test

for all tests; *Transmission Sump Temp= >160F*
Hydraulic Sump Temp= >150F
Engine Oil Sump Temp= >200F

Emissions Test (pre catalyst)

Condition	Engine Speed	%CO	HC, ppm	%O2	Nox, ppm
Idle	760	0.31	133	0.58	440
High Idle	2850	0.38	27	0.48	1100
Tilt Relief	2670	0.41	51	0.45	3500
Trans Stall	2120	0.48	85	0.41	4250

Performance Tests

Acceleration through 50ft from standstill

Condition	method 1	method2	method3
No Load	4.78	4.57	5.45
Loaded (5000lbs)	5.18	4.98	6.15

method 1: Lift brake and Jab throttle at same time
method 2: Lift brake and wait until transmission engagement, then Jab throttle
method 3: Lift brake, Jab throttle and Pull + Hold Tilt Relief at same time

Drawbar Pull

Ave Force (lbs)	6002

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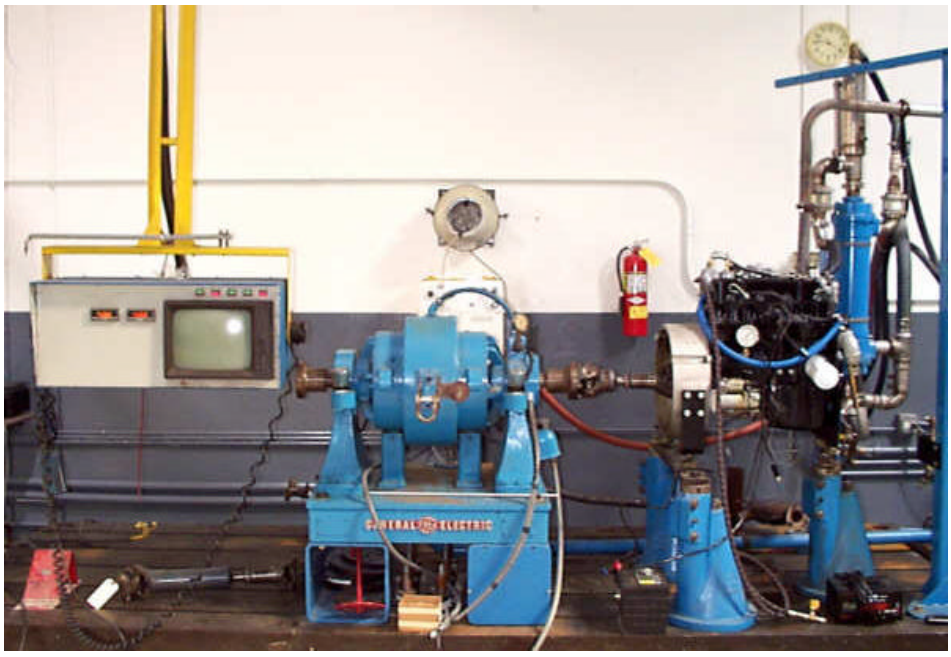
Appendix 3: In vehicle Performance Testing con't

Closed Loop Test *for all tests; Transmission Sump Temp≥160F*
Hydraulic Sump Temp≥150F
Engine Oil Sump Temp≥200F

Emissions Test (post catalyst)

Condition	Engine Speed	%CO	HC, ppm	%O2	Nox, ppm
Idle	730	0.00	35	-	0
High Idle	2880	0.01	14	0.20	150
Tilt Relief	2760	0.01	11	0.10	300
Trans Stall	2130	0.15	58	0.12	475

THIS IS TO ILLUSTRATE PRE-CATALYST vs POST-CATALYST EMISSIONS ONLY
PERFORMANCE TESTING CAN BE FOUND ON POST CATALYST SHEET



Engine dynamometer

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Example of closed loop system

Same real estate as an open loop system

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Further Improvements - Further enhancements to the Commander II software after the preceding case study enables further emission reductions and further enhances transient performance of the engine.

TEST NUMBER:	990514		**ENGINE:**	3.0 GM		**MIXER:**	CA100	
DATE:	5/14/99		**CONTROL:**	CDP 2		**GOV:**	Velocity	
TIME:	11am		**CAT:**	Impco				
NOTES:	Modal test using next generation CDP II feedback system. Improved EGO waveform shaping capabilitie							
	MODE 1	**MODE 2**	**MODE 3**	**MODE 4**	**MODE 5**	**MODE 6**	**MODE 7**	**WEIGHTED**
WEIGHT FACTOR	6%	2%	5%	32%	30%	10%	15%	100%
TIME, seconds	300	300	300	300	300	300	300	
SPEED, rpm	2423	1625	1625	1625	1625	1625	790	
% MAX. TORQUE	25%	100%	75%	50%	25%	10%	0%	
TORQUE, ft-lb	34	136	99.4	66.2	33.1	13.3	0.0	
TORQUE, N-m	46.1	184.4	134.8	89.8	44.9	18.0	0.0	
POWER, hp	15.7	42.1	30.8	20.5	10.2	4.1	0.0	13.36
weighted power (hp)	0.9	0.8	1.5	6.6	3.1	0.4	0.0	**13.36**
WORK, hp-h	1.3	3.5	2.6	1.7	0.9	0.3	0.0	
POWER, kw	11.7	31.4	22.9	15.3	7.6	3.1	0.0	9.96
WORK, kw-h	1.0	2.6	1.9	1.3	0.6	0.3	0.0	
LAMBDA								
NOx, g	0.043	0.746	0.6	0.107	0.007	0.646	0.058	0.1571
CO, g	0.418	40.275	11.333	5.351	0.125	0.027	0.009	3.1511
HC, g	0.056	0.252	0.348	0.172	0.047	0.073	0.169	0.1276
#pump revs	6000	5995	5999	5999	6000	6001	5999	
#pump revs/300sec	6000	6000	6000	6000	6000	6000	6000	
correction factor	1.0000	0.9992	0.9998	0.9998	1.0000	1.0002	0.9998	
weighted Nox (g)	0.003	0.015	0.030	0.034	0.002	0.065	0.009	**0.1572**
weighted CO (g)	0.025	0.806	0.567	1.713	0.038	0.003	0.001	**3.1522**
weighted HC (g)	0.003	0.005	0.017	0.055	0.014	0.007	0.025	**0.1276**
NOx, g/h	0.52	8.95	7.20	1.28	0.08	7.75	0.70	1.8857
CO, g/h	5.02	483.30	136.00	64.21	1.50	0.32	0.11	37.8132
HC, g/h	0.67	3.02	4.18	2.06	0.56	0.88	2.03	1.5311
weighted Nox (g/h)	0.03	0.18	0.36	0.41	0.03	0.78	0.10	**1.8858**
weighted CO (g/h)	0.30	9.67	6.80	20.55	0.45	0.03	0.02	**37.8258**
weighted HC (g/h)	0.04	0.06	0.21	0.66	0.17	0.09	0.30	**1.5313**
							NOx, g/hp-h	**0.14**
							CO, g/hp-h	**0.21**
							HC, g/hp-h	**0.11**
							NOx+HC, g/hp-h	**0.26**
							NOx+HC, g/kW-h	0.34
NOx+HC, g/hp-h	0.08	0.28	0.37	0.16	0.06	2.10	non-corrected	***0.26***
NOx, g/kw-h	0.04	0.29	0.31	0.08	0.01	2.53	non-corrected	*0.19*
CO, g/kw-h	0.43	15.40	5.93	4.20	0.20	0.11	non-corrected	*3.80*
HC, g/kw-h	0.06	0.10	0.18	0.14	0.07	0.29	non-corrected	*0.15*
NOx+HC, g/kw-h	0.10	0.38	0.50	0.22	0.08	2.81	non-corrected	***0.34***

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Field Testing

To Further validate performance and durability in a field environment, IMPCO has performed additional testing in manufacturing facilities. The following data has been collected from a performance and durability validation test we are running on the IMPCO Commander II and catalyst.

TRUCKS CONFIGURED AT MANUFACTURING FACILITY

Truck No.	Hours	Engine Size
101	86.5	4.3 L GM
103	57	3.0 L GM
108	340	3.0 L GM
119	9.9	4.3 L GM

* **COMMANDER II AND CATALYST INSTALLED**
* **3.0 GM FUEL SYSTEM COMPONENTS WERE RECONFIGURED WITH REGULATOR MOUNTED CLOSED TO MIXER TO IMPROVE TRANSIENT RESPONSE**
* **4.3 GM FUEL SYSTEM COMPONENTS WERE LEFT AS FACTORY CONFIGURED**
* **DUTY CYCLE CENTERED ON 50 DEGREES (ALL MODELS)**
* **ALL SPECIFICATIONS TAKEN WITH TRUCK HOT (+150 TRANS TEMPERATURE)**

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DURABILITY DATA AS OF AUGUST 30,1999

TRUCK NO.	HOURS	OPERATION	CO	HC	DUTY CYCLE CONTROL
100	2152	IDLE TILT RELIEF TRANS STALL	.33 .31 .22	49 49 64	60 50 30
101	2066	IDLE TILT RELIEF TRANS STALL	.07 .50 .15	36 64 67	50 50 50
103	2254	IDLE TILT RELIEF TRANS STALL	.01 .01 .04	14 15 20	60 50 40
108	3820	IDLE TILT RELIEF TRANS STALL	.01 .04 .03	24 17 15	60 50 50
119	1038	IDLE TILT RELIEF TRANS STALL	.07 .40 .05	53 49 47	50 50 50

DURABILITY DATA AS OF NOVEMBER 2,1999

TRUCK NO.	HOURS	OPERATION	CO	HC	DUTY CYCLE CONTROL
100	2806	IDLE TILT RELIEF TRANS STALL	.33 .39 .50	42 37 70	50 45 30
101	2300	IDLE TILT RELIEF TRANS STALL	.25 .60 .15	75 70 85	60 60 60
103	2837	IDLE TILT RELIEF TRANS STALL	.01 .05 .08	6 22 33	50 50 40
108	4722	IDLE TILT RELIEF TRANS STALL	.00 .02 .11	5 0 31	55 40 35
119	1400	IDLE TILT RELIEF TRANS STALL	.00 .35 .11	63 53 63	60 50 40

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SUMMARY OF CONFIGURATION HOURS

TRUCK NO.	HOURS AS OF 2 NOV 99	HOURS ON FUEL SYSTEM	HOURS ON CDP II	HOURS ON CATALYST
100	2806	2806	2571	NA
101	2300	2300	2213.5	2300
103	2837	2837	2780	1560
108	4722	4722	4382	4722
119	1400	1400	1390.1	1400